Jet Quenching and Radiative Energy Loss in Dense Nuclear Matter

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In this report [1] we reviewed two recent approaches to the problem of non-Abelian radiative energy energy loss in dense but finite QCD matter. In the first section, we highlighted some of the striking new high p_T phenomena observed for the first time in $A+A$ reactions at RHIC with $\sqrt{s} > 100$ AGeV. An interesting pattern of hadron suppression, already beginning at moderate $p_T > 3$ GeV, was seen in the hadron flavor dependence of single inclusive spectra, in the large azimuthal asymmetry, and in the preliminary two-hadron correlations. We interpret these phenomena as manifestations of jet quenching in ultra-dense matter produced in such reactions. Our predictions for these phenomena in both approaches are reviewed in later sections and depend on the energy loss, $\Delta E = \int dx\, dE/dx$, of fast quarks and gluons propagating through rapidly expanding QCD matter. The two approaches, GLV and WW/WOGZ reviewed here, provide a systematic way to compute ΔE via an opacity or higher twist expansion in finite nuclear matter. Elsewhere reviewed asymptotic approaches such as the BDMS/Z/SW are designed for applications to "thick" or macroscopic media at asymptotic energies. An analytic approximation to the sum of the infinite multiplehis series can be summed to all orders (or equivalently all twist parton-parton correlations) to reproduce the standard Glauber t collision series is obtained through an approximate color dipole quantum diffusion analogous to the Moliere series in electrodynamics. The complications due to finite kinematic bounds are neglected. As shown in, the phenomenological applications of the asymptotic expressions tend to overpredict quenching at RHIC and lead to a too rapid variation of the suppression factor with p_T, inconsistent with the RHIC data. In our approach, on the other hand, the opacity series is computed to arbitrary order in opacity for applications to finite opacity systems where the non-Gaussian (Rutherford) tails of distributions are not yet eclipsed by the approximate Gaussian small p_T component. In addition, our expressions can be applied to arbitrary 3D expanding and time dependent media such as created in nuclear collisions.

The GLV reaction operation approach is based on a general algebraic recursive method that describes the propagation and interaction of systems through dense nuclear matter, taking into account the severe destructive LPM interference effects due to the long formation times of ultra-relativistic partons. It provides a means to compute the multiple collision amplitudes to any order χ^n in the opacity $\chi = \int dz \sigma\rho$. So far it has been successfully applied to obtain solutions for the nuclear broadening and the final state medium induced radiation resulting from multiple elastic and inelastic projectile scatterings. The range of applicability of the calculations can be significantly extended by careful treatment of kinematic bounds.

The final state double differential distributions of jets and gluons are presented as an infinite series in powers of the mean number of scatterings χ. For elastic scatterings this series can be summed to all orders (or equivalently all twist parton-parton correlations) to reproduce the standard Glauber theory result, but more general than the simple color dipole approximation used in asymptotic analyses. For inelastic processes, a closed sum to all orders can unfortunately only be carried out in the dipole approximation as in BDMS/Z/SW for most recent developments). However, our analytic expressions at any finite order in opacity can be evaluated numerically. Numerical evaluation of the expressions through the first three orders (up to twist 8) has been carried out for phenomenological applications. Each power in opacity adds a twist 2 parton-parton correlation. Future work via this approach includes computation of multiple gluon emission beyond the Poisson approximation and the broadening and radiation of dipole-like, possibly heavy, $\bar{q}q$ systems. Applications to heavy quark energy loss including both the Ter-Mikayelian gluon dispersion effects as well as the "dead cone" effect are also underway.

The WW approach extends the calculation of energy loss to include the positive feedback (jet acceleration) due to absorption of thermal gluons in the medium. Absorption counteracts the induced energy loss for jet momenta less than the typical thermal energy scale $\sim 3T$. In an expanding hydrodynamic medium with transverse boost rapidity η_T we expect that this absorption feedback contribution is blue shifted to higher momenta $p_T \sim 3Te^{\eta_T}$. Thus jet quenching cannot suppress the spectrum below the local equilibrium hydrodynamic limit. The jet quenching pattern from RHIC data may have already provided the first tomographic evidence that initial parton densities on the order of 100 times nuclear matter density were achieved in $Au+Au$ collisions.

[1] M. Gyulassy, I. Vitev, X.-N. Wang, and B.-W. Zhang (2003), nucl-th/0302077.